Simulation of valve-controlled accumulator in electro-hydraulic variable speed drive system

Ming Xu [1, a], Sen Sun [1, b] and Jiaqi Zhang [1, c]

[1]School of Mechanical Engineering, Hangzhou Dianzi University, Hangzhou 310018, China;

[a]xumzju@163.com, [b]291280303@qq.com, [c]1272440531@qq.com

Abstract

A passive hydraulic accumulator and an active flow control valve were combined to constitute a semi-active device, which can actively release hydraulic energy for a faster actuator response or absorb hydraulic energy for a good energy-saving performance. The valve-controlled accumulator (VCA) was placed into a variable speed drive system to test the its main parameters to the system dynamic performance, and then get its optimal design method. The simulations of accumulator different precharge pressures and volumes were implemented to compare the system dynamic performance, including actuator response, speed tracking error and power consumption， so as to verify the optimal design method of the VCA.

Keywords

Accumulator; Valve-controlled accumulator; Precharge pressure; Volume; Variable speed drive.

1. Introduction

Hydraulic accumulator is usually used as energy storage device in hydraulic system [1-5]. However, the hydraulic accumulator is a passive component, because the hydraulic energy released or absorbed depends entirely on the pressure difference between accumulator inside and outside, as well as the hydraulic oil volume released or absorbed cannot be controlled, which may result in excessive absorption of hydraulic pressured oil so that delay the actuator response, or release too much pressured oil so that cause the hydraulic shock. Combining the flow control valve with the accumulator to constitute a VCA is a promising way to solve the above problems. The passive hydraulic accumulator and the active flow valve were combined to a semi-active device, whose functional principles are discussed as follows: (1) When the accumulator outside pressure is smaller than the inside pressure, as well as the supplied pressured oil by hydraulic pump is less than the demanded pressured oil by the hydraulic actuator, the flow valve opens, and the accumulator releases hydraulic pressured oil so as to accelerate the actuator response. (2) When the accumulator outside pressure is larger than the inside pressure, as well as the supplied pressured oil by hydraulic pump is much than the demanded pressured oil by the hydraulic actuator, the flow valve opens, and the accumulator absorbs hydraulic pressured oil so as to improve energy-saving efficiency. (3) In the remaining cases, the flow control valve closes, and the VCA does not work.

The VCA unit is promising to be applied in a hydraulic volumetric speed control system or a volumetric-throttle compound speed control system, because the nature of these two types of drive systems is that the supplied pressured oil always tracks the demanded pressured oil [6-10], it is easy to find the condition of insufficient supply of hydraulic pressured oil, and the dynamic response of hydraulic actuator often impossible to be guaranteed.

2. Simulations and Discussions

To test the optimal design method of VCA, two types of simulations using AMESim are implemented, which are adjustable accumulator precharge pressure and adjustable accumulator volume. Fig.1 shows the simulation model, and Table.1 shows the main parameters.

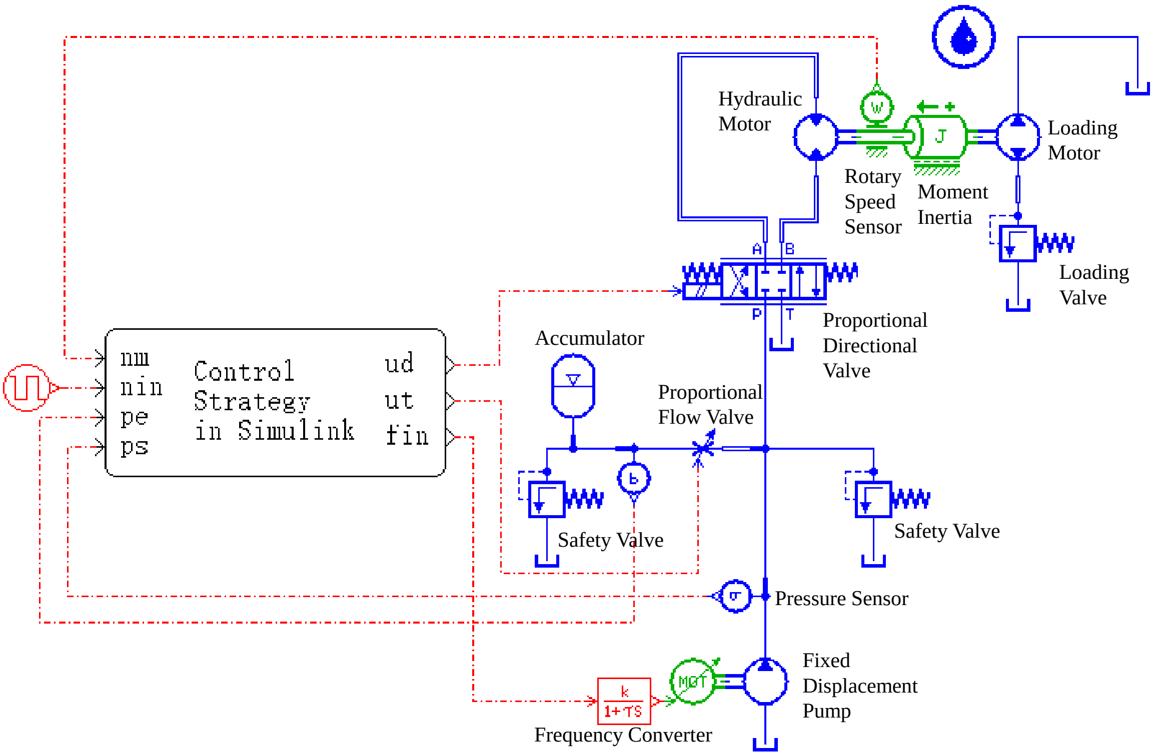

Fig.1 Simulation model of VCA in electro-hydraulic variable speed drive system

Table 1 Main parameters in simulation

Parameter	Value	Parameter	Value
Pump -frequency converter gain coefficient (K)	30 r/(min·Hz)	Moment Inertia (J_t)	0.1 kgm^2
Frequency time constant (T)	0.15	viscous damping coefficient (B_m)	0.0167Nm/(r/min)
Pump displacement (D_p)	20 mL/r	static friction torque (Ts)	4.47 Nm
Motor displacement (D_m)	30 mL/r	Colombo friction torque (Tc)	13.3 Nm
Safety pressure of relief valve	10 MPa	Hydraulic oil density	850 kg/m^3

2.1 Accumulator precharge pressure

When analyzing the effect of accumulator precharge pressure, the accumulator volume is fixed at 6.3 L. The expected speed of hydraulic motor is set to a square wave signal with a period of 10 s, and with a maximum speed of 600 r / min, 400 r / min and 800 r / min, respectively. The expected minimum speed is 0 r / min. And the loading pressure is set to 3 MPa.

Fig.2 shows the motor speed comparisons when accumulator precharge pressure of is 1 MPa, 3 MPa, 5 MPa, 7 MPa and 9 MPa, respectively. When the accumulator precharge pressure is less than or equal to 7 MPa, the hydraulic motor response becomes better as the accumulator precharge pressure increases. Although the loading pressure is 3 MPa, the pressure difference between hydraulic motor two chambers is actually about 7 MPa because of the friction torque. When the accumulator precharge pressure is close to 7 MPa, the regulation effect of VCA is the best. When the precharge pressure is 9 MPa, although the response is the fastest in the initial stage of actuator acceleration, its response becomes the slowest in later period since there is not enough hydraulic oil volume to support the whole accelerating time in accumulator.

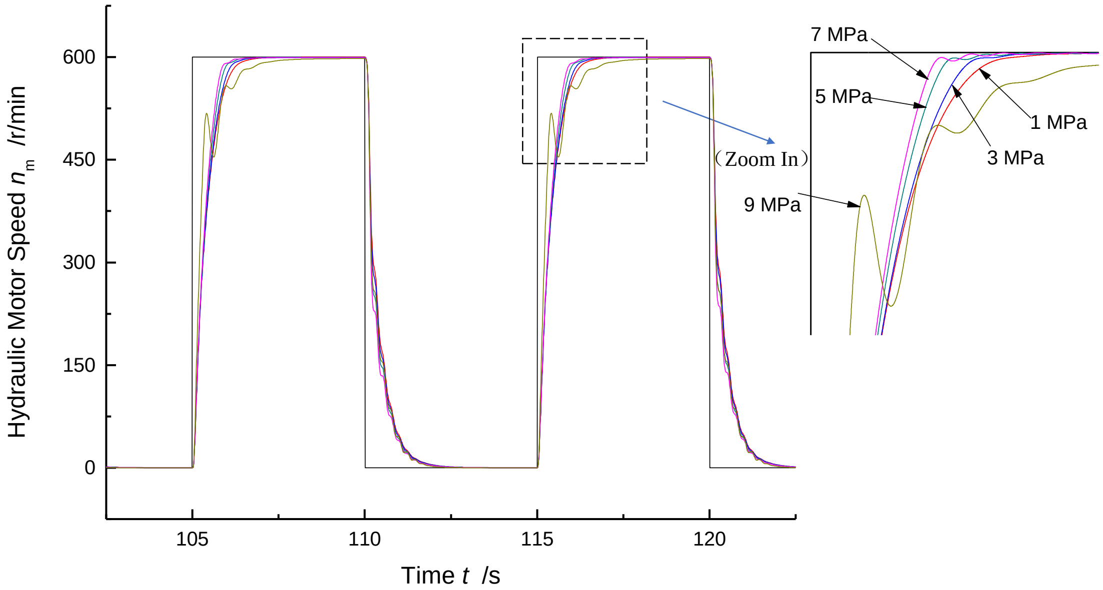

Fig.2 Response comparisons under different accumulator precharge pressure (600 r / min)

Fig.3 shows the compensated flow between the VCA and main system on the conditions of different accumulator precharge pressures. The positive flow indicates that the VCA releases pressured oil, and the negative indicates that the VCA absorbs pressured oil. As shown in Fig.3, when the accumulator precharge pressure is less than or equal to 7 MPa, as the precharge pressure increases, the more pressured oil compensating to system. When the accumulator precharge pressure is 9 MPa, a flow impact was caused in the initial stage of actuator acceleration. But the accumulator lost its most pressured oil, and cannot improve actuator response anymore.

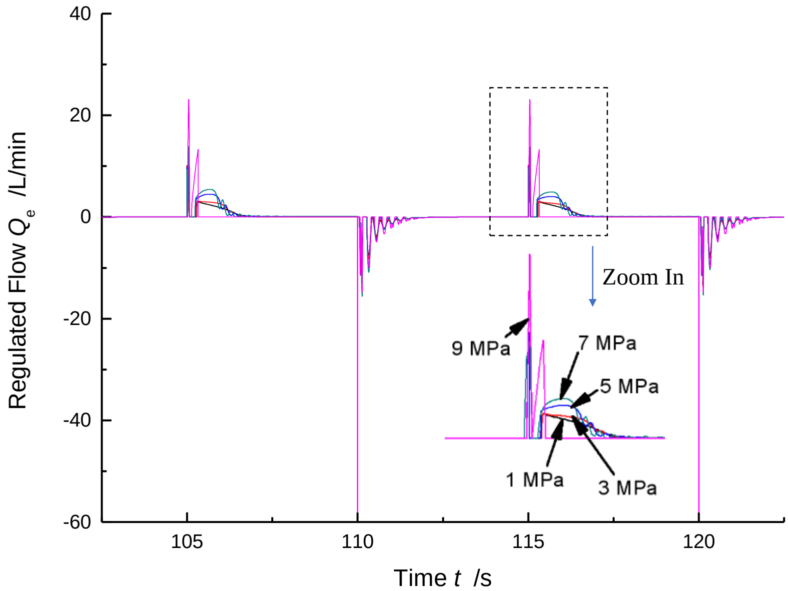

Fig.3 Regulated flowrate by VCA

Table.2 shows the speed tracking error and average power consumption in different accumulator precharge pressure. As the accumulator precharge pressure increases, the mean square error of motor speed decrease. The power consumption data in different precharge pressure is basically the same. The mean square error of motor speed is defined as $\frac{1}{n}\sum_{i=0}^{n}(n_{in}(i)-n_m(i))^2$, n is the numerical value of sampling times.

Table 2 Speed tracking error and power consumption –(600r / min)

Accumulator precharge pressure	1 MPa	3 MPa	5 MPa	7 MPa	9 MPa
Mean Square Error (r2/min2)	16482.36	16147.06	15181.61	14092.80	13450.83
Average Power Consumption (kW)	1.069	1.066	1.059	1.055	1.087

On the basis of above analysis, the accumulator precharge pressure is less than or equal to the load pressure, the system performance improves with the precharge pressure increasing. According, a conclusion can be drawn that the accumulator precharge pressure equals to the load pressure is the best.

2.2 Accumulator volume Influence

Fig.4 compares the motor response under different accumulator capacities. The motor response improved with the accumulator capacity increases, where is the larger accumulator volume the better dynamic system performance.

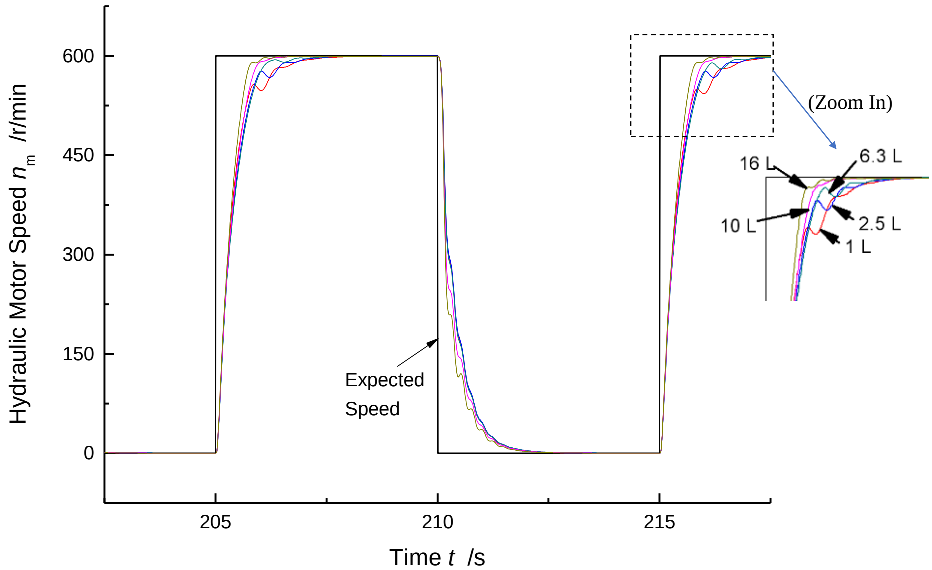

Fig.4 Response Comparison under different accumulator volumes (600 r / min)

Table 3 shows the speed tracking error and average power consumption in different accumulator capacity (600 r/min). As the accumulator volume increases, the mean square error of the motor speed error decreases. The average power consumption is basically the same, it will not enlarge with increased accumulator volume.

Table 3 Speed tracking error and power consumption (600 r/min)

Accumulator volume	1 L	2.5 L	6.3 L	10 L	16 L
Mean Square Error (r^2/min^2)	15590.76	15919.88	15747.52	14547.63	13306.14
Average Power Consumption (kW)	1.071	1.070	1.068	1.058	1.054

3. Conclusion

The larger accumulator capacity the better. However, the volume increase has no obvious effect on motor response to a certain extent. The accumulator capacity also needs to be considered the place and installing restriction in practical applications. For the accumulator precharge pressure, it is the best that the precharge pressure equals to load pressure. However, the load pressure always changes according to different load, viscous damping, expected actuator response, leakage et al. It requires a comprehensive consideration to arrive at a reasonable accumulator precharge pressure.

For proportional flow valve in VCA, a faster response and larger flow gain coefficient are the first principles. The safety valve is chosen according to the highest allowable pressure in VCA. And the response is the fast the better. In addition, the VCA should be connected to the main circuit as close as possible to reduce the total pipeline and cavity volume, so as to increase the system natural frequency, thereby improving the system's dynamic response.

Acknowledgements

This research is supported by Zhejiang Provincial Natural Science Foundation of China (Grant No. LY16E050004).

References

[1] Lovrec D, Tic V., Tasner T. Dynamic behavior of different hydraulic drive concepts-comparison and limits [J]. International Journal of Simulation Model, 2017, 16(3), p448-457.

[2] Hua-yong YANG, Min PAN. Engineering research in fluid power: a review. Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering), 2015, 16(6) , p427-442.

[3] Ristic, M... Conversant technology – New key aspects: Development of variable speed drives. *Proceedings of International Fluid Power Conference*, Dresden, 2008, p93-108.

[4] Yajun Fan, Anle Mu, Tao Ma. Modeling and control of a hybrid wind-tidal turbine with hydraulic accumulator [J]. Energy, 2016, (112), p188-199.

[5] Peng-Yu Zhao, Ying-Long Chen, and Hua Zhou. Simulation Analysis of Potential Energy Recovery System of Hydraulic Hybrid Excavator [J]. 2017, 18(11), p1575-1589.

[6] Jan Siebert, MarcoWydra, Marcus Geimer. Efficiency Improved Load Sensing System—Reduction of System Inherent Pressure Losses [J]. Energies, 2017, 10, p941.

[7] Oscar R. Peña Michael J. Leamy. An efficient architecture for energy recovery in hydraulic elevators [J]. International Journal of Fluid Power, 2015, p1-16.

[8] T.M.I. Mahlia, T.J. Saktisahdan, A. Jannifar et al. A review of available methods and development on energy storage: technology update [J]. Renewable and Sustainable Energy Reviews, 2014, 33, p532-545.

[9] Ajit Kumar, K Dasgupta, J Das. Analysis of decay characteristics of an accumulator in an open-circuit hydrostatic system with pump loading [J]. Proceedings of the Institution of Mechanical Engineers Part I—Journal of Systems & Control Engineering,2017, 231(4) , p312-326.

[10] Burecek, A, Hruzik, L, Vasina, M. Simulation of accumulator influence on hydraulic shock in long pipe [J]. Manufacturing & Industrial Engineering, 2014,14, p1–4.